when the air sampler is turned on. Plankton samples were obtained from the surface film to a depth of about 2.5 cm.

The boat has successfully obtained neuston samples in shallow water (7.5 to 15 cm), and small-volume samples of air. Similar models could be constructed for specific sampling duties.

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## Intensity Fluctuations of a Relativistically Expanding Source

Abstract. *It is shown that the relation between the size of an object and the period of a fluctuation in its brightness must be modified if the surface whose brightness is fluctuating is expanding at a relativistic velocity, in the sense that faster fluctuations are possible for the expanding surface.*

It is well known that the size of a stellar object limits the frequency and amplitude with which the apparent brightness can vary (*1–3*). In a recent paper, Rees (*4*) has discussed the apparent diameter of a relativistically expanding source and shows that this diameter can grow with a velocity much greater than *c*. In Rees's model, radio variations are due principally to changes in the apparent diameter of the source, not to fluctuations in the surface brightness. However, if $t$ is the time since the explosion of the object, that is, the time since an extrapolation of the apparent diameter passed through zero, then the logarithmic rate of change of the apparent area with respect to time is $2/t$ regardless of whether the expansion is relativistic or not. Rees obtains rapid variations, therefore, by assuming his source to be very young (about 3 years old, in his example). It is shown below that a relativistically expanding surface whose brightness is a function of time is not constrained by Terrell's conclusion that of a fluctuation of period $T$ in an object with constant radius $R$ only a fraction $cT/\pi R$ is observable. Rapid fluctuations in the brightness of a relativistically expanding object are therefore possible for two reasons: that the object is young or has a young component, as proposed by Rees, or that the surface brightness is fluctuating, as suggested here.

Consider, as does Terrell (*1*), an object whose surface brightness is fluctuating. The fluctuations will be damped because of the retardation of the signal from the limb of the object with respect to the signal from the center of the disc. For a relativistically expanding object, however, the relation between the diameter of the object and the retardation to the limb is modified, and more rapid fluctuations are possible. The first thing to be done is to define what is meant by the diameter. One might take the retarded diameter, as suggested by Terrell (*2*), the size of the observable disc, assumed resolvable, as proposed by Rees, or a diameter computed from the light output and a surface brightness in the rest frame of the apparent surface. Since the retarded diameter is not observable, it will not be considered. The disc size is easiest to use, and is, therefore, discussed first.

Since detailed calculation will be required for each particular model, only a very schematic model is discussed below. Consider first a non-expanding star, and imagine that it is dark, but that it emits a short pulse of light. An observer will see the emitted light spread over a time $R/c$, so that the time over which the pulse is spread, divided by the diameter, is

$$\Delta t/D = 1/2c \quad \text{(stationary)}$$

Now consider a relativistically expanding spherical surface whose radial velocity is $\beta c$ which also emits a pulse of light at a time when the radius of the star in its own rest frame is $R$. If $\rho$ is the distance from the observer to the center of the star, the observer will first see the light at a time $(\rho - R)/c$ after it is emitted. The apparent limb of the star is only a distance $(1 - \beta)R$ further from the observer than the center of the disc, and so the light pulse will cease a time $(1 - \beta)R/c$ after it begins. On the other hand, the apparent diameter of the disc, if it can be resolved, is $2R/\gamma$, where, $\gamma = (1 - \beta^2)^{-\frac{1}{2}}$, so that

$$\Delta t/D = \gamma(1 - \beta)/2c$$
$$\text{(expanding, resolved)}$$

It is evident that for a relativistically expanding surface the pulse is spread over a much shorter time than for a stationary one.

Terrell's considerations have attracted so much attention, however, not because they may give rise to a contradiction between the fluctuation rate and size of the resolved disc of a quasar, but rather because they may give rise to a contradiction between the fluctuation rate and the luminosity of the object. The surface brightness is fixed by other considerations and the diameter calculated from the luminosity and this brightness exceeds the upper bound calculated from the fluctuation rate. Since the number of photons leaving the star is proportional to $4\pi R^2$ and, neglecting intergalactic absorption, all the photons leaving the star will appear at some possible observation site, the diameter computed by an observer from the number of photons he sees and an emittance he has computed will be $2R$, greater by a factor $\gamma$ than the diameter he would see if he could resolve it. The time delay is unaltered, so that now

$$\Delta t/D = (1 - \beta)/2c$$
$$\text{(expanding, calculated),}$$

an even smaller result.

The Doppler shift of the emitted light varies between $\gamma$ at the apparent limb and $\gamma(1 + \beta)$ at the center of the disc. Another factor of approximately $\gamma^{-\frac{1}{2}}$ would, therefore, appear in $\Delta t/D$ if $D$ were computed from the energy output rather than from the number of photons observed. Since the spread of the Doppler shift is so great, it is clear that the considerations above cannot apply to the optical line spectrum. A careful application to the radio spectrum would require an assumption about the spectral index and a detailed calculation of Doppler shifts and relativistic solid angle transformations across the disc of the object. Qualitatively, however, a velocity within one part in 1000 of the velocity of light would be required to eliminate the discrepancy of a factor of 1000 (*3*) between the diameter of CTA 102 deduced from the radio luminosity and that deduced from the fluctuation rate. This discrepancy, however, is deduced from measurements which have not been confirmed by other workers, and is not thought reliable (*5*). No other clear contradiction of this sort is known to me.

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## Bioelectric Phenomena Related to Protein-Fixed Charge in a Crab Nerve Fiber

Abstract. *The bioelectrical characteristics of a crab nerve fiber subjected to solutions containing the impermeant anions ferrocyanide, glutamate, or ethanolsulfate substituted for chloride include prolonged slow depolarizations that elicit prolonged trains of impulses superimposed on the plateau portion. Propionate and nitrate depress repetitive firing while thiocyanate has only a slight effect. Nerves treated with ferrocyanide lose potassium and gain sodium, which fact may account for their depolarization. On the other hand, studies with interference microscopy reveal shift by ferrocyanide in the interference fringe pattern of the sheath material; this suggests a reorientation of fixed charges in the protein layers by direct action of the anion on these layers. This may also account for the electrical manifestations observed.*

Although bioelectrical phenomena arising in excitable tissue have been generally related to cation concentrations and movements across cell membranes (*1*), considerable attention has also been drawn to the possibility that fixed charges in the membrane may contribute to these phenomena (*2*). We present evidence, from experiments with single crustacean axons, concerned with the effect of anions substituted for chloride in the surrounding medium; our data supports the fixed-charge hypothesis.

When the impermeant anion ferrocyanide is substituted for chloride in the medium surrounding skeletal muscle, remarkably prolonged, spontaneously occurring plateau depolarizations are recorded (*3*); these are not unlike the responses obtained from crustacean motor axons subjected to a potassium-rich medium or to one containing veratrine (*4*). Since the transmembrane characteristics of the crustacean axon are now well known (*5*), this preparation seems to be very suitable for examination of the effects of anions substituted for chloride in the medium surrounding a single nerve fiber. This is particularly so in the light of recent studies, with interference microscopy, relating structural change to the effects of potassium-rich media on these nerve fibers (*6*).

Table 1. Percentage changes of intracellular concentrations of sodium and potassium of crab nerve caused by immersion in test solutions.

| Test solution | Preparations (No.) | Sodium | Potassium |
|---|---|---|---|
| Isotonic ferrocyanide | 15 | +58 ± 15 | −31 ± 5 |
| Potassium-free ferrocyanide | 1 | +75 | −59 |
| Potassium-excess (130 m*M*) ferrocyanide | 1 | + 8 | −56 |
| Isotonic propionate | 3 | + 4 ± 2 | − 8 ± 2 |
| Calcium-free | 2 | +56 | −25 |

Single axons were isolated from the walking limbs of the crab (*Callinectes sapidus*) and mounted either for the three-electrode flow-tube method of electrical recording (*5*) or in the special chamber for interference microscopy (*6*). The chloride in *Homarus* physiological solution (*7*) was replaced by the anions ferrocyanide, glutamate, ethanolsulfate, nitrate, propionate, or thiocyanate; in the solution containing ferrocyanide, isomolarity was maintained by the addition of sucrose.

Typical dual-beam oscilloscopic recording of a single nerve fiber subjected to the ferrocyanide solution are presented in Fig. 1. The upper trace shows the pulse of the applied current; the lower trace shows the resulting membrane potential response. A slow, spontaneous depolarization occurred, indicated by the rise in the base line (Fig. 1, A1–A3), and ultimately the stimulus current (Fig. 1, A1) triggered a repetitive response not only during the duration of the pulse, but one which continued for seconds or even minutes after termination of the pulse. This response was superimposed on a prolonged plateau depolarization (Fig. 1, A3). By hyperpolarization (Fig. 1B) with a continuously applied current directed inward, the long trains of impulses and plateau could be abbreviated, the duration being inversely proportional to the amplitude of hyperpolarization. These data agree well with those on frog muscle (*3*).

The potential recordings in Fig. 1, A1, clearly show the development of the slow response with the action potentials superimposed (spikes). The S-shaped, rising phase of this prolonged depolarization is also characteristic of the slow response obtained in potassium-rich media. Nitrate and propionate simply depressed activity of the nerve fiber, increasing the critical firing level slightly and eliminating the normal repetitive firing pattern of these axons during a depolarizing stimulus. Thiocyanate caused only a slight depression of activity.

Because of the marked resemblance of the spontaneously occurring depolari-

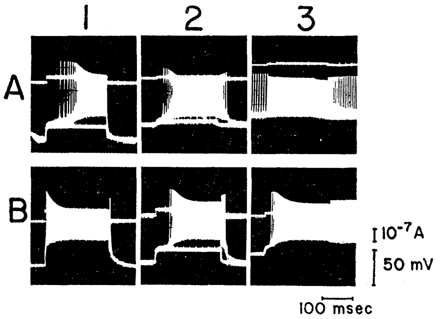

Fig. 1. Dual-beam oscilloscopic recordings from a single axon subjected to *Homarus* solution, with ferrocyanide substituted for chloride. Top trace indicates current stimulating pulse; bottom trace, membrane potential deflections. Recordings taken immediately after application of ferrocyanide (A1) and at 1-minute intervals (A2 and A3). Note development (S-shaped curve) of slow response (A1) and concomitant decline in the amplitude of the action potential with increased frequency. Row B illustrates the effect of strong (B1 and B2) and weak (B3) hyperpolarization.